CLAIMS

1. A method of using a pulsed laser for program-controlled dicing of a substrate comprising at least one layer, the method comprising the steps of:

   a. providing program control means and associated data storage means for controlling the pulsed laser;

   b. providing in the associated data storage means a laser cutting strategy file of at least one selected combination of pulse rate, pulse energy and pulse spatial overlap of pulses produced by the laser at the substrate to restrict damage to the respective at least one layer while maximising machining rate for the at least one layer;

   c. providing in the laser cutting strategy file data representative of at least one selected plurality of scans of the respective at least one layer by the pulsed laser necessary to cut through the respective at least one layer when the pulsed laser is operating according to the respective at least one combination stored in the laser cutting strategy file; and

   d. using the laser under control of the program control means driven by the laser cutting strategy file to scan the at least one layer with the respective at least one selected plurality of scans at least to facilitate dicing of the substrate such that a resultant die has at least a predetermined die strength and a yield of operational die equals at least a predetermined minimum yield.

2. A method as claimed in claim 1, wherein the steps b and c of providing a laser cutting strategy file comprise, for each of the at least one layer, the steps of:

   b1. varying at least one of a combination of pulse rate, pulse energy, pulse spatial overlap to provide a respective combination;

b2. measuring a cutting rate of the respective layer using the respective combination;

b3. examining the layer to determine whether damage is restricted to a predetermined extent;

b4. dicing the substrate and measuring yield of the resultant die;

b5. measuring die strength of the resultant die;

b6. creating a laser cutting strategy file of a selected combination which maximises cutting rate while resulting in a yield of operational die which have at least the predetermined minimum yield and for which the die have at least the predetermined die strength;

c1. scanning the at least one layer using the selected combination to determine a plurality of scans necessary to cut through the layer; and

c2. storing the selected plurality of scans in the laser cutting strategy file.

3. A method as claimed in claim 2, wherein the die strength is measured using a Weibull die strength test.

4. A method as claimed in any of claims 1 to 3, wherein the step d of using the laser to scan the at least one layer includes providing a galvanometer-based scanner.

5. A method as claimed in any of claims 1 to 4 wherein the step d of using the laser to scan the at least one layer includes providing a telecentric scan lens for scanning a laser beam from the laser across the substrate and the step of providing a laser cutting strategy file comprises the steps of;

d1. mapping a laser energy density received in a focal plane of the telecentric scan lens to produce a laser energy density map of a field of view of the

telecentric lens using the selected combination of pulse rate, pulse energy and pulse spatial overlap of pulses;

d2. storing the laser energy density map as an array in the storage means; and

d3. using the laser energy density map to modify, with the control means, at least one of the pulse repetition rate and the pulse energy of the selected combination to produce a constant laser energy density at scanned points in the field of view at the substrate.

6. A method as claimed in claim 5, wherein the step of mapping a laser energy density comprises using a laser power meter to measure laser energy density at representative locations within the field of view of the telecentric lens.

7. A method as claimed in any of the preceding claims wherein the step of providing a selected combination comprises providing a selected combination which restricts thermal loading of the material of the respective layer to restrict mechanical stress to a predetermined maximum.

8. A method as claimed in any of the preceding claims, wherein the selected combination is used for less than the selected plurality of scans, which corresponds to the selected combination, to machine a layer to be cut and the layer is scanned for further scans up to the selected plurality using a combination which will not significantly machine an underlying layer such that substantially no machining occurs of the underlying layer should the laser continue to scan the substrate after the layer to be cut has been cut through.

9. A method as claimed in claim 8, used for scribing a substrate through the layer to be cut for subsequent mechanical dicing of the substrate.

10. A method as claimed in any of the preceding claims wherein the substrate includes an active layer, wherein the step of providing a selected combination to restrict damage to the at least one layer comprises providing a selected

combination which does not significantly affect the subsequent operation of active devices in the active layer.

11. A method as claimed in claim 10, wherein the step of providing a selected combination which does not significantly affect the subsequent operation of active devices in the active layer comprises providing a combination which does not cause significant cracks to propagate through the active layer.

12. A method as claimed in any of the preceding claims, wherein the step of providing a selected combination comprises the steps of:

b7. providing an initial combination at which the laser machines the substrate at an initial rate which does not cause significant crack propagation due to thermal shock at an ambient temperature, and such that a temperature of the substrate is raised by the machining after a predetermined plurality of scans of the substrate by the laser to a raised temperature above ambient temperature;

b8. and providing a working combination at which the laser machines the substrate at a working rate, higher than the initial rate, which does not cause significant crack propagation due to thermal shock at the raised temperature;

and step d of machining the substrate includes:

d4. machining an initial depth of the substrate using the initial combination for at least the predetermined plurality of scans; and

d5. machining at least part of a remaining depth of the substrate using the working combination.

13. A method as claimed in any of the preceding claims, wherein an energy of at least a first of the plurality of scans is lower than an energy of succeeding scans

of the plurality of scans such that a generation of surface micro-cracks is less than would otherwise be produced.

14. A method as claimed in any of the preceding claims, wherein an energy of at least a final of the plurality of scans is lower than an energy of preceding scans of the plurality of scans such that backside chipping of the substrate is less than would otherwise be produced.

15. A method as claimed in any of the preceding claims, wherein energy of the plurality of scans is varied between scans to facilitate removal of debris generated during dicing of the substrate, conveniently by increasing laser energy with increasing machining depth to remove debris for a dice lane.

16. A method as claimed in any of the preceding claims including the further steps of:

e. providing gas handling means to provide a gaseous environment for the substrate;

f. using the gaseous environment to control a chemical reaction with the substrate at least one of prior to, during and after dicing the substrate to enhance a strength of the resultant die.

17. A method as claimed in claim 16, wherein the step of providing gas handling means includes providing gas delivery head means for delivering gas substantially uniformly to a cutting region of the substrate to facilitate substantially uniform cutting of the substrate.

18. A method as claimed in claims 16 or 17, wherein the step of providing gas handling means comprises providing means to control at least one of flow rate, concentration, temperature, type of gas and a mixture of types of gases.

19. A method as claimed in any of claims 16 to 18, wherein the step of providing a gaseous environment comprises providing a passive inert gas environment for substantially preventing oxidation of walls of a die during machining.

20. A method as claimed in any of claims 16 to 18, wherein the step of providing a gaseous environment comprises providing an active gas environment.

21. A method as claimed in claim 20 wherein the step of providing an active gas environment comprises etching walls of a die with the active gas to reduce surface roughness of the walls and thereby improve the die strength.

22. A method as claimed in claims 20 or 21, wherein the step of providing an active gas environment comprises etching walls of a die with the active gas substantially to remove a heat affected zone produced during machining, and thereby improve the die strength.

23. A method as claimed in any of claims 20 to 22, wherein the step of providing an active gas environment comprises reducing debris, produced during machining, adhering to surfaces of machined die.

24. A method as claimed in any of the preceding claims, comprising the further step after dicing of scanning an edge of the resultant die with the laser with sufficient energy to heat sidewalls of the resultant die to reduce surface roughness thereof and thereby increase die strength of the resultant die.

25. A method as claimed in any of the preceding claims for producing die with rounded corners by scanning the laser beam along a curved trajectory at corners of the die using a galvanometer based scanner, wherein the selected combination is adapted to maintain the selected pulse spatial overlap between consecutive laser pulses around an entire circumference of the die.

26. A method as claimed in any of the preceding claims, wherein the selected combination is adapted to deliver pulses at an arcuate portion or corner of the

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die such that substantially no over-cutting or undercutting generating a defect at the arcuate die edge or corner occurs.

27. A method as claimed in any of the preceding claims to form a tapered dice lane having arcuate walls tapering inwards in a direction away from the laser beam by varying a width of the dice lane as the laser scans through the substrate wherein the selected combination is modified to give a finely controlled taper and smooth die sidewalls, and thereby increase die strength of the resultant die.

28. A method as claimed in any of the preceding claims, wherein the laser is a Q-switched laser device.

29. A method as claimed in any of the preceding claims, wherein a laser beam from the laser is directed by rotatable mirrors.

30. A method as claimed in any of the previous claims, wherein the substrate is mounted on a tape and energy of final scans of the laser is controlled substantially to prevent damage to the tape.

31. A method as claimed in claim 30, wherein the tape is substantially transparent to ultraviolet radiation.

32. A method as claimed in claim 31, wherein the tape is polyolefin-based.

33. A program-controlled substrate dicing apparatus for dicing a substrate comprising at least one layer, the apparatus comprising: a pulsed laser; program control means and associated data storage means for controlling the pulsed laser using a laser cutting strategy file, stored in the data storage means, of at least one respective selected combination of pulse rate, pulse energy and pulse spatial overlap of pulses produced by the laser at the substrate and data representative of at least one respective selected plurality of scans of the respective at least one layer by the pulsed laser necessary to cut through the respective at least one layer; telecentric scan lens means for scanning a laser beam from the pulsed laser across the substrate; and laser power measuring means for mapping a laser energy density received in a focal plane of the telecentric scan lens to produce a laser energy density map of a field of view of the telecentric lens using the

selected combination of pulse rate, pulse energy and pulse spatial overlap of pulses for storing the laser energy density map as an array in the data storage means for modifying the at least one respective selected combination to compensate for irregularities, introduced by the telecentric lens, of laser energy density at the substrate, such that in use a resultant die has at least a predetermined die strength and a yield of operational die equals at least a predetermined minimum yield.

34. An apparatus as claimed in claim 33, wherein the program control means includes control means for varying at least one of pulse rate, pulse energy and pulse spatial overlap for controlling the laser subject to the at least one respective selected combination.

35. An apparatus as claimed in claims 33 or 34 further comprising gas handling means for providing a gaseous environment for the substrate for controlling a chemical reaction with the substrate at least one of prior to, during and after dicing the substrate to enhance strength of the resultant die.

36. An apparatus as claimed in claim 35, wherein the gas handling means includes gas delivery head means for uniformly delivering gas to a cutting region of the substrate.

37. An apparatus as claimed in claim 35 or 36, wherein the gas handling means comprises control means for controlling at least one of flow rate, concentration, temperature, type of gas and a mixture of types of gases.

38. An apparatus as claimed in any of claims 35 to 37, wherein the gas handling means is arranged to provide an inert gas environment for substantially preventing oxidation of walls of a die during machining.

39. An apparatus as claimed in any of claims 35 to 37, wherein the gas handling means is arranged to provide an active gas environment.

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40. An apparatus as claimed in claim 39, wherein the gas handling means is arranged to etch walls of a die with the active gas to reduce surface roughness of the walls, and thereby increase die strength.

41. An apparatus as claimed in claim 39, wherein the gas handling means is arranged to etch walls of a die with the active gas substantially to remove a heat affected zone produced during machining, and thereby increase die strength.

42. An apparatus as claimed in claim 39, wherein the gas handling means is arranged to etch walls of a die with the active gas to reduce debris, produced during machining, adhering to surfaces of machined die.

43. An apparatus as claimed in any of claims 33 to 42 further comprising a galvanometer-based scanner for producing die with rounded corners by scanning a laser beam along a curved trajectory at corners of the die, wherein the selected combination is arranged to maintain the selected pulse spatial overlap between consecutive laser pulses around an entire circumference of the die.

44. An apparatus as claimed in any of claims 33 to 43, wherein the selected combination is arranged to control laser pulse delivery at an arcuate portion or corner of a die edge such that substantially no over-cutting or undercutting occurs which would generate a defect at the die edge.

45. An apparatus as claimed in any of claims 33 to 44 arranged for forming a tapered dice lane having arcuate walls tapering inwards in a direction away from the laser beam by varying a width of the dice lane as the laser scans through the substrate wherein the selected combination is modified to give a finely controlled taper with smooth die walls, and thereby increase die strength of the resultant die.

46. An apparatus as claimed in any of claims 33 to 45, wherein the laser is a Q-switched laser device.

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47. An apparatus as claimed in any of claims 33 to 46, including rotatable mirrors for directing a laser beam from the laser on the substrate.
48. An apparatus as claimed in any of claims 33 to 47, arranged for a substrate mounted on a tape, wherein the laser is controlled in final scans of the substrate not substantially to damage the tape.
49. An apparatus as claimed in claim 48, wherein the tape is substantially transparent to ultraviolet light.
50. An apparatus as claimed in claim 49, wherein the tape is polyolefin-based.